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13. ABSTRACT (Maximum 200 words)

Research was carried out in a number of areas of multivariate analysis. New methods have been proposed in the theory of M-estimation to safeguard against outliers. Asymptotic distributions have been derived under a minimal set of assumptions.

Bootstrap techniques are extended to nonstandard situations. Theoretical and computational aspects of bootstrap are reviewed.

Exact tests have been developed to test the significance of parent-offspring correlations.

New methods have been devised for multitarget tracking. The new methods are found to be satisfactory as they depend on minimal assumptions and involve simpler computational algorithms.

In the area of probability, Edgeworth expansions have been extended to cover the cases where some of the variables are not continuous, which is considered as a major advance from the point of view of practical applications.

A new differential geometric structure of a statistical model is proposed which is more general and more informative than those considered earlier. The methods are applied to study properties of estimates of parameters.

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FINAL REPORT

Research under support from AFOSR 91-0242

The present report covers the research work done during the period 1/31/91-1/31/93. Detailed reports for the work done in the previous calendar years have been submitted on due dates. The Center for Multivariate Analysis (CMA) issued 38 technical reports during the above period. A list of technical reports together with individual abstracts is given in Appendix A to this report. The list of visitors to the CMA is given in Appendix B.

The broad areas of investigation include the following:

1. Robust inference based on M-estimation
2. Bootstrap
3. Multitarget tracking
4 Probability
5. General multivariate techniques
6. Rao's score tests
7. Differential geometric methods in statistics.

Brief accounts of important contributions made to each of these areas are given below.

1. M-estimation

Technical Reports: 92-14, 92-17, 92-23

In previous papers issued by the CMA, a general theory of M-estimation was developed using a convex discrepancy function. The results were proved under minimal assumptions. The theory was then extended to cover discrepancy functions which can be expressed as the difference of two convex functions. A further extension is made by considering a very general discrepancy function ρ which is non-increasing in $(-\infty,0]$ and non-decreasing in $[0,\infty)$ and is such that

$$\rho(ku) \leq c(k)\rho(u)$$

for any constant k, where $c(k)$ is a constant depending only k. The function so defined provides robustness against outliers.

2. Bootstrap

Technical Report: 92-16

Theoretical and computational aspects of the bootstrap methodology are reviewed. The consistency and accuracy of the bootstrap methodology are discussed in detail. The main thrust of research is to develop bootstrap methodology in nonstandard situations.

3. Multitarget tracking

Technical Reports: 92-04, 92-18, 92-19, 92-28, 92-30

The objective of our research program is to provide a comprehensive plan of research for signal (or target) detection, estimation, and tracking, all of which are strategically important for battle management. At the Center for Multivariate Analysis (CMA), we devote ourselves to establishing a comprehensive theory and methodology for signal detection, estimation, and tracking. Under the support of the AFOSR, we have developed a general information criterion for signal detection and established consistency and limiting distributions for signal estimates under various models

One of the major problems in multitarget tracking is data association. At each time point we have estimates of positional coordinates of different targets, and the problem is to sort them out into sequences of estimates over time such that each sequence refers to the positions of a particular target over time and thus provide its track. In a series of papers, methods have been developed to obtain estimates at any time point ensuring the proper association with estimates at the previous stage, i.e., the problem of data association is embedded in the problem of estimation itself. In a recent paper, an algorithm is developed for the above method by using the maximum likelihood method of estimation (to achieve Cramer-Rao lower bound) and refining the estimates via the Kalman filter. Simulation results indicate good performance even under low signal to noise ratios.

A general theory is developed for computing the posterior density of the dynamical parameters (position, velocity and acceleration) of a single target at time t given the observations made up to time t under various assumptions on the prior distribution of the initial parameters. The possibility of treating the initial parameters as unknown constants and using their estimates is also explored.

A theory of linear prediction is developed which uses only the second order moments of the noise vector and which is independent of the initial parameters of a target. The general and linear prediction theories are extended to the multitarget case and a satisfactory solution is obtained for multitarget tracking through a probabilistic data association scheme.

4. Probability

Technical Reports: 92-01, 92-06, 92-10, 92-20, 92-21, 92-31, 92-33, 92-34, 92-38

A major achievement in the area of probability is the proof of the validity of the Edgeworth expansion for functions of vector sample means under minimal conditions. Our proof covers the cases, not considered in earlier work, where some of the components of the vector sample means are counting variables, and considerably enlarges the scope of the Edgeworth expansion. Some applications have been made to survival analysis where one of the components (such as the number of people living at a given time) is a counting variable.

Berry-Esseen bounds provide an upper limit to the error in using normal approximation to the distribution of the sample mean in sampling from an infinite population. Recently, an upper bound is found for the distribution of the sample mean when sampling is done from a finite population without replacement. At the CMA, we have solved the long standing open problem of finding an upper bound to the distribution of the t -statistic in sampling from a finite population without replacement.

The weak laws of large numbers have been extended to random weighted sums of random elements in Banach spaces.

Using spectral analysis of multivariate Markoff random fields on Z^d where Z is the space of integers and the dimension $d \geq 1$, the Markoff property is characterized in terms of the best linear interpolation, and the estimates of the interpolation coefficients are obtained from estimated inverse autocovariances.

The concept of bispectral analysis is extended to non-stationary processes. Some examples have been considered.

5. General multivariate techniques

Technical Reports: 92-07, 92-08, 92-09, 92-35

The following problems in multivariate analysis have been considered in the above technical reports.

(i) Testing the null hypothesis that the correlations between mother and offspring and father and offspring are zero. We have data on parents and children whose number may vary from family to family. Exact small sample tests have been obtained. Upto now only asymptotic results were known.

(ii) Optimum tests for main effects in a linear model are derived when there is spatial dependence for the errors. The results have applications in agricultural field experiments, marine geology, quality engineering and electronics.

(iii) The maximum likelihood estimate of the parent-sib interclass correlation and other parameters are obtained when the between sib correlation matrix has a circular structure.

(iv) New methods have been devised for scaling ordinal categories in a contingency table in such a way that the order of the scales is consistent with the ranks of the ordinal categories.

6. Rao's score test

Technical Reports: 92-32, 92-36

In a paper published in 1948, C. R. Rao introduced score tests which have wide applicability. Since then, a large number of papers have been written comparing the power properties of score tests with other competing tests. Some optimum properties of score tests have been discussed with special reference to Bartlett-type adjustment and restricted alternatives.

7. Differential geometric methods in statistics

Technical Reports: 92-24, 92-25, 92-26, 92-27

Differential geometric methods in statistical inference have been introduced by C. R. Rao in 1945. The interest in this area is revised only 15 years ago, and there have been numerous contributions during the past few years. At the CMA, some new lines of research have been started.

(i) A new differential geometric structure of a statistical model is proposed, which is more general and more informative than those considered earlier.

(ii) The concept of Gauss curvature of a statistical model is introduced and its relationship to Fisher information matrix has been established.

(iii) The concept of information loss due to Fisher and Rao in the case of estimation of a single parameter has been extended to the multiparameter case.

(iv) The efficiency of Bayes estimators has been discussed using differential geometric techniques.

APPENDIX A

LIST OF TECHNICAL REPORTS AND ABSTRACTS

CENTER FOR MULTIVARIATE ANALYSIS

January 1992 - December 1992

92-01 Gutti Jogesh Babu. EDGEWORTH EXPANSIONS IN NON-REGULAR CASES AND THEIR APPLICATIONS TO BOOTSTRAP, January 1992 (*Air Force*)

Edgeworth expansions for sums, of non-identically distributed random vectors and of random vectors with lattics and non-lattice coordinates are reviewed. their applications to errors-in-variables models, least absolute deviation estimators etc., are presented. Applications to bootstrap are also discussed.

92-02 Robert L. Fountain and C. Radhakrishna Rao. FURTHER INVESTIGATIONS OF BERKSON'S EXAMPLE, March 1992 (*Air Force*)

Berkson's bioassay problem is investigated in detail. In addition to maximum likelihood estimators and Berkson's proposed minimum logit χ^2 estimators, several modified estimators are considered. Two Rao-Blackwellized estimators - a conditional mean and conditional median, given the sufficient statistics - as well as Amemiya's bias-corrected and partially bias-correct estimators are included. The estimators are compared with respect to bias, variance, mean squared error, and Pitman's measure of closeness. The experiment is examined at four different levels of the parameters, and is re-examined subject to a monotonicity condition imposed on the sample space. The results provide a new insight into the controversy over the comparison of minimum χ^2 and maximum likelihood estimators.

92-03 J. Subramani. ESTIMATION OF VARIANCE COMPONENTS IN LINEAR MODELS - A LINEAR PROGRAMMING APPROACH, June 1992 (*Air Force*)

The present paper describes a method of estimating variance components in linear models through linear programming problem approach. Consequently the resulting estimates of the variance components are nonnegative, which is a desirable property for the estimates of the variance components. The procedure is also illustrated with the help of numerical examples.

92-04 C. R. Rao, C. R. Sastry and B. Zhou. TRACKING THE DIRECTION OF ARRIVAL OF MULTIPLE MOVING TARGETS, June 1992 (*Army*)

In this work we focus on the problem of tracking the direction-of-arrival (DOA) of multiple moving targets. The targets are assumed to be moving with constant accelerations subject to minor random

perturbaticns and emitting narrow band signals that impinge on an array of passive sensors. Estimates of the DOA vector of the targets are obtained from the sensor data based on the maximum likelihood (ML) principle in such a way that the association between the estimates made at different time points is maintained. At each stage, the current ML estimates of DOA are treated as measurements and refined via a Kalman filter and tracking is accomplished without the need to perform unduly heavy computations. An efficient strategy for dealing with closed by spaced targets is also presented. Finally, the performance of our tracking agorithm is illustrated via computer simulations.

92-05 Guantao Chen, M. Bhaskara Rao and Warren E. Shreve. CAN ONE LOAD THE DICE SO THAT THE SUM IS UNIFORMLY DISTRIBUTED? June 1992 (*Air Force*)

Let $X_1, X_2, \ldots, X_n$ be n independent random variables each taking values in $\{1,2,\ldots,m\}$. Let $S = X_1 + X_2 + \ldots + X_n$. The question is whether it is possible to choose a distribution for each X_i so that S has a uniform distribution over $\{n, n+1, \ldots, nm\}$. In th', note, we establish a critical inequality on the probability distribution of S from which a negative answer follows to the question.

92-06 E. B. Fosam, C. R. Rao and D. N. Shanbhag. A PROBLEM OF DOWNTON REVISITED, June 1992 (*Air Force*)

A major error in Downton (1969) is revealed and some relevant comments are made, including those on Arnold and Ghosh (1976) and Klebanov (1980).

92-07 Raja Velu and M. Bhaskara Rao. TESTING OF HYPOTHESES ABOUT INTERCLASS CORRELATIONS IN TWO PARENTS FAMILY DATA, July 1992 (*Air Force*)

The main focus of this paper is on testing of certain hypotheses in the environment of familial data. Each member of the target population has a mother, a father and some offsprings. The number of offsprings could vary from family to family. A certain quantitative characteristic of the family is under investigation. In this paper, we derive an exact test for testing the hypothesis that the interclass correlations between the mother and offspring and between the father and offspring are zero. Many test procedures available in the literature in this connection are asymptotic in nature. We also discuss the connection between our problem and the multivariate familial data problem. We follow the linear model approach for the exact tests.

92-08 Ravindra Khattree and Dayanand N. Naik. OPTIMUM TESTS FOR NESTED DESIGNS WITH SPATIAL DEPENDENCE, July 1992 (*Air Force*)

Nested designs with correlated error structures occur naturally in spatial experiments. For these designs with balanced data and derivation of the optimum tests is considered for the significance of a fixed effect or a variance component. The error is assumed to have a circular covariance structure. It is shown that whenever these tests exist, they coincide with the likelihood ratio tests and also with the usual analysis of variance tests.

92-09 Ravindra Khattree and Dayanand N. Naik. ESTIMATION OF INTERCLASS CORRELATION UNDER CIRCULAR COVARIANCE, July 1992 (*Air Force*)

The maximum likelihood estimates of the parent-sib interclass correlation and other parameters are obtained, when the between sibs correlation matrix has a circular structure. The problem of testing the hypotheses about interclass correlation is considered.

92-10 C. Radhakrishna Rao D. N. Shanbhag. EXTENDED STABILITY THEOREMS FOR THE INTEGRATED CAUCHY FUNCTIONAL EQUATION, July 1992 (*Air Force*)

The stability theorems for the integrated Cauchy functional equation, given by Rao and Shanbhag (1989, 1990) are extended and their applications are briefly discussed. Included amongst corollaries to the theorems are the main results of Gu and Lau (1984).

92-11 Manzoor Hussain and M. Bhaskara Rao. ON IMPROVING THE QUALITY OF MINIMAL INCOMPLETE BLOCK DESIGNS, July 1992 (*Air Force*)

The randomized complete block design is an ideal design for comparing the effects of treatments over a population of experimental units arranged in blocks. In the case when one is unable to entertain a randomized complete block design, it is a sound idea that one should construct incomplete block designs with some desirable properties such as connectedness(every treatment contrast is estimable) and balancedness.

The main focus of this paper is to start with what are called minimal designs, i.e., those designs with a minimum number of experimental units needed to be connected, and set upon improving these designs towards achieving balancedness.

92-12 C. R. Rao, M. S. Srivastava and Yanhong Wu. SOME ASPECTS OF QUALITY CONTROL METHODS, July 1992 (*Air Force* and *Army*)

This paper reviews quality control methods when the quality characteristic can be measured by a continuous variable. There are three aspects of quality control: 1) Statistical Process Control (SPC),

2) Automatic Process Control (APC), and 3) Lot Inspection (LI). The first two methods are called on-line quality control methods and are applied to control the quality of a production process while in operation. The third method is usually used after production and uses a sampling device to inspect the finished products for defectives.

92-13 Rupa Mitra and M. Bhaskara Rao. WHEN THE KAPLAN-MEIER ESTIMATOR OF THE SURVIVAL FUNCTION IS REALLY A SURVIVAL FUNCTION? July 1992 (*Air Force*)

In this note, an expression for the probability that the Kaplan-Meier estimator of the survival function is random censorship model is a survival function is derived. It is shown that this probability has a simple form in the case of proportional hazards.

92-14 Z. D. Bai C. R. Rao Y. H. Wu. A NOTE ON M-ESTIMATION OF MULTIVARIATE LINEAR REGRESSION, June 1992 (*Army*)

M-estimates of the parameters in a linear model are obtained by minimizing the sum of functions of residuals. The function called the "discrepancy function" and denoted by ρ, is chosen to provide robust estimates. In this paper we suggest the choice, $\rho = \rho_1 - \rho_2$, where ρ_1 and ρ_2 are convex functions. By choosing ρ_1 and ρ_2 suitably, we can generate a wide variety of discrepancy functions which can be used in practice. There is an added advantage that the conditions placed on ρ_1 and ρ_2 and hence on ρ are much milder than those considered in the literature on M-estimation.

92-15 Xin Wei Jia and M. Bhaskara Rao. ON WEAK CONSISTENCY IN LINEAR MODELS WITH EQUI-CORRELATED RANDOM ERRORS, July 1992 (*Air Force*)

A new estimator in linear models with equi-correlated random errors is postulated. Consistency properties of the proposed estimator and the ordinary least squares estimator are studied. It is shown that the new estimator has smaller variance than the usual least squares estimator under some conditions. It is observed that the new estimator tends to be weakly consistent in many cases where the usual least squares estimator does not.

92-16 Gutti Jogesh Babu and C. Radhakrishna Rao. BOOTSTRAP METHODOLOGY, June 1992 (*Air Force* and *Army*)

Theoretical and computational aspects of the bootstrap methodology are reviewed. Consistency and asymptotic accuracy of the bootstrap methods are discussed in detail. The methods for non-smooth functions, significance tests, construction of confidence intervals, are also reviewed. A brief discussion of bootstrap methods for censored, sample

survey, regression, autoregressive and time series models is also given. Situations where the bootstrap method fails are indicated. A summary of Bayesian bootstrap methods is given.

92-17 Z. D. Bai, Z. J. Liu and C. Radhakrishna Rao. ON THE STRONG CONSISTENCY OF M-ESTIMATES IN LINEAR MODELS UNDER A GENERAL DISCREPANCY FUNCTION, June 1992 (*Air Force* and *Army*)

Huber (1964) considered the estimation of the parameter β in the linear model $Y_i = X_i'\beta+\epsilon_i$, $i = 1,\ldots,n$, by minimizing $\Sigma\rho(Y_i-X_i'\beta)$, where ρ is a suitably chosen "discrepancy function". Properties of such estimates known as M-estimates have been considered by several authors for particular choices of ρ. In this paper we consider a general ρ which in non-increasing in $(-\infty,0]$ and non-decreasing $[0,\infty)$ and establish strong consistency of the M-estimate. Such a choice of ρ covers most of the cases considered by earlier writer.

92-18 C. R. Rao, C. R. Sastry and Bin Zhou. SOME RECENT CONTRIBUTIONS TO MULTITARGET TRACKING, June 1992 (*Army*)

In this paper, the most recent contributions in multitarget tracking are reviewed. The areas covered include efficient algorithms for data association and estimation, and tracking of the directions of arrival (DOA) using data from an array of sensors. An introduction to the symmetric measurement equation (SME) filter approach to multitarget tracking is also provided. Finally, some suggestions are made for future research.

92-19 C. R. Rao. SOME STATISTICAL PROBLEMS IN MULTITARGET TRACKING, June 1992 (*Army*)

In tracking a single target, dynamical and observational equations are used to estimate, via Kalman filter, the positional coordinates of the target at different time points, and the trajectory is obtained by joining the successive positional coordinates over time. In the case of multiple targets, we generally do not have separate observations on each target. At any time point, we have a set of measurements without the information as to which measurement belongs to which object. The statistical problem is that of estimating the positional coordinates of the individual targets from such mixed up data using the information provided by the dynamical equations and the previous estimates.

92-20 V.V. Bapeswara Rao and M. Bhaskara Rao. A THREE-DOOR GAME SHOW AND SOME OF ITS VARIANTS, July 1992 (*Air Force*)

A four-door version of a popular three-door game show has been considered in this paper and an optimal solution is derived. The general n-door version is also considered.

92-21 Xiangchen Wang and M. Bhaskara Rao. CONVERGENCE IN THE r-th MEAN AND SOME WEAK LAWS OF LARGE NUMBERS FOR RANDOM WEIGHTED SUMS OF RANDOM ELEMENTS IN BANACH SPACES, July 1992 (*Air Force*)

Let X_n, $n\geq 1$ be a sequence of random elements in a Banach space B and a_{nk}, $k\geq 1$, $n\geq 1$ an array of real random variables. Some necessary and sufficient conditions for the randomly weighted sums of the form $\sum_{k\geq 1} a_{nk}X_k$, $n\geq 1$ to converge in probability and also in the r-th mean are given. Some results in the literature in this environment follow from our results. Moreover, some characterizations of Banach spaces of type p and B-convexity emerge from these results.

92-22 Manzoor Hussain, C. Radhakrishna Rao and M. Bhaskara Rao. MINIMAL ROW-COLUMN DESIGNS, July 1992 (*Air Force*)

In this paper, we are concerned with the construction of Row-Column designs which are treatment-connected and treatment-balanced. To start with, we introduce Minimal Row-Column designs, i.e., those designs which require minimum number of experimental units to stay treatment-connected. We study, in detail, a particular Minimal Row-Column design. We also introduce a class of Minimal Row-Column designs in which there is less imbalance. Finally, we suggest some methods of enlarging Minimal Row-Column designs so that the enlarged designs become nearly balanced.

92-23 Z. D. Bai and Y. Wu. LIMITING BEHAVIOR OF M-ESTIMATORS OF COEFFICIET VECTOR IN HIGH DIMENSIONAL REGRESSION MODELS. II. SCALE-INVARIANT CASE, July 1992 (*Army*)

Consider the linear model

$$y_{in} = x_{in}'\theta_{no}+e_{in}, \quad 1 \leq i \leq n$$

where x_{in} is a sequence of known p-vectors, $\theta_{no} \in R^p$ is an unknown vector of regression coefficients, $\{e_{in}\}$ is a sequence of iid random errors and $p = p_n$ tends to infinity as $n \to \infty$.

Let ρ be a discrepancy function and $\hat{\theta}_n$ and $\hat{\sigma}_n$ be M-estimates obtained by minimizing

$$\sum_{i=1}^{n} \rho[(\sigma^{-1}(y_{in}-x_{in}'\theta)) + \log \sigma].$$

Further, let $\tilde{\theta}_n$ be an M-estimate obtained by minimizing

$$\sum_{i=1}^{n} \rho(\tilde{\sigma}_n^{-1}(y_{in}-x_{in}'\theta)).$$

The properties of $\hat{\theta}_n$ and $\tilde{\theta}_n$ are studied as $n \to \infty$.

92-24 Min Deng. DIFFERENTIAL GEOMETRIC STRUCTURE OF A STATISTICAL MODEL, August 1992 (*Army*)

In this paper be introudce a differential geometric constructions in probability spaces, which is different from the information metric introduced by Rao. The new Riemann metric plays a very important role in discussing curvatures and Fisher information matrix. It is suggested that the new Riemann metric may yield results in statistical inference. We also show that the new Riemann metric is asymptotically equivalent to the Riemann metric proposed by Rao (1945).

92-25 Min Deng. CURVATURES AND THE INFORMATION MATRRIX, August 1992 (*Army*)

In this paper, we introduce the concept of Gauss curvature of a statistical model. In this connection, a natural question asked. Does Gauss curvature and Fisher information matrix have any relationship? The paper provides an answer to this question. Also other curvatures of a statistical model are introduced and the relationshhips between these curvatures and Fisher informatio are established.

92-26 Min Deng. CURVATURE AND SECOND ORDER ASYMPTOTIC PROPERTIES OF THE GENERALIZED BAYES ESTIMATORS FOR THE LOCATION FAMILY, August 1992 (*Army*)

In this paper, we find the second order asymptotic density function of the generalized Bayes estimator for a truncated location family, and give the upper bound for concentration probability for 3/2-th order asymptotically median unbiased (AMU) estimators. It is pointed out that the curvature of this family plays a very important role in the second order asymptotic properties of the generalized Bayes estimators for a truncated location family. Also one of the results obtained here has been approximation than Akahira's result and another is equivalent to his. Finally, asymptotic generalized Bayes estimators up to the second order for the two parameters truncated location family are derived.

92-27 Min Deng. INFORMATION LOSS IN ESTIMATION OF PARAMETERS, August 1992 (*Army*)

In this paper, we investigate the asymptotic loss of information matrix in estimation of parametes in a multiparameter family. This extends the results of Fisher, Rao and Efron on the loss of information in the one parameter case to several parameters. In particular, we consider two-parameter family of distributions and computer the information loss for a number of methods of estimation like maximum likelihood minimum chisquare, etc.

92-28 C. Radhakrishna Rao and Bin Zhou. CLOSED FORM SOLUTION TO THE ESTIMATES OF DIRECTIONS OF ARRIVAL USING DATA FROM AN ARRAY OF SENSORS, August 1992 (*Army*)

Closed form solution to the estimates of directions of arrival (DOAs) of signals is obtained through solving a polynomial equation of degree equal to the number of distinct signals. The coefficients of the polynomial are estimated by expressing the condition that the vector of coefficients augmented by zeroes belongs to the noise subspace or is orthogonal to the signal subspace.

92-29 Dayanand N. Naik and Ravindra Khatree. TESTING FOR RANDOM EFFECTS IN ANALYSIS OF COVARIANCE MODEL, August 1992 (*Air Force*)

We derive the locally best invariant tests for the random effects under unbalanced one way classification set up, when the data on a single covariant are variable. The distributions of the test statistics involved are also derived.

92-30 Debasis Kundu and Nandini Kannan. ESTIMATION OF DIRECTION OF ARRIVAL OF SIGNALS, August 1992 (*Army*)

In this paper, the authors proposed some modifications to the existing methods of estimatioin of the unknown directions of arrival of signals from several sources using both the data vectors and its conjugate. The strong consistency of the estimators have been established. Simulation results that illustrate the performance of the different methods are presented.

92-31 C. Radhakrishna Rao. CURRENT TRENDS OF RESEARCH IN STATISTICS SMALL SAMPLE ASYMPTOTIC, RESAMPLING TECHNIQUES AND ROBUSTNESS, June 1992 (*Army*)

In many statistical problems, it is often difficult to evaluate the exact distribution of a statistic. In such cases we resort to asymptotic methods. The paper surveys some recent results on asymptotic expansions of the distribution of a statistic, with successive terms providing improvement in accuracy but decreasing in

magnitudes with orders of successive powers of $1/n$ or $1/\sqrt{n}$, where n is the sample size. It also describes the methods of jackknife and bootstrap for making approximate computations of some distributional aspects of estimators and test criteria. Recent work on robust inference is briefly mentioned.

92-32 Rahul Mukerjee. RAO'S SCORE TEST: RECENT ASYMPTOTIC RESULTS, September 1992 (*Army*)

This article reviews some recent asymptotic results on Rao's score test. A third-order optimality property of this test, under contiguous alternatives, has been discussed. Some approaches towards a Bartlett-type adjustment for Rao's statistic have been summarized. A few related open problems are also indicated.

92-33 Y. Yuan and T. Subba Rao. CHARACTERISATION AND ESTIMATION FOR MULTIVARIATE MARKOV RANDOM FIELDS BY SPECTRAL METHODS, October 1993 (*Army*)

This paper is concerned with spectral analysis of multivariate Markov random fields on Z^d, where Z is the space of integers and the dimension $d \geq 1$. The Markov property is characterised in terms of best linear interpolation, and estimates of the interpolation coefficients are obtained from estimated inverse autocovariances. We study the asymptotic properties of the spectral estimates, and provide empirical examples with simulated Markov random field data.

92-34 M. B. Priestley and M. M. Gabr. BISPECTRAL ANALYSIS OF NON-STATIONARY PROCESSES, October 1993 (*Air Force* and *Army*)

92-35 C. Radhakrishn Rao and Paula M. Caligiuri. ANALYSIS OF ORDERED CATEGORICAL DATA THROUGH APPROPRIATE SCALING, October 1992 (*Air Force and Army*)

This article offers a new method for rescaling ordered categories when the data are in the form of either frequencies (i.e., contingency tables) or multiple choice responses (e.g., items on a scale). The natural order of the qualitative scale points is maintained while the optimal points are quantified. Scaling procedures and examples for both types of ordered categories are given.

92-36 C. Radhakrishna Rao and Rahul Mukerjee. TESTS BASED ON SCORE STATISTICS: POWER PROPERTIES AND RELATED RESULTS, October 1992 (*Army*)

This paper begins with a brief review of recent developments on higher order asymptotic properties of the score test under unrestricted alternatives. Then we consider restricted alternatives and propose

some versions of the score test which are shown to be locally optimal under the criteria of average power and maximinity. Finally, some related open issues including those connected with the M-theory have been mentioned.

92-37 Ravindra Khattree and Dayanand N. Naik. ESTIMATION OF VARIANCE COMPONENTS IN STAGGERED NESTED DESIGNS, October 1992 (*Air Force*)

In this article, we present various approaches to the variance component estimation for a general p-stage random effects staggered nested design. In addition to ANOVA and maximum likelihood estimation, two new approaches are introduced. The main features of these approaches are their simplicity and ability to always yield the nonnegative estimates of various variance components. The performance of various procedures are compared for several meaningful criteria by simulation.

92-38 C. R. Rao and L. C. Zhao. BERRY-ESSEEN BOUND FOR FINITE POPULATION t-STATISTIC, November 1992 (*Air Force*)

In this paper, the Berry-Esseen bound for finite-population t-statistic is established under some mild conditions.

APPENDIX B

Visitors to the Center for 1992

G. Budhwar	U.S.A.	2 months
M. Deng	Canada	2 months
S. Handa	India	2 days
M. Hussain	U.S.A.	2 months
X. W. Jia	U.S.A.	2 months
R. Khattree	U.S.A.	1 month
K. Kraft	U.S.A.	1 week
Z. J. Liu	U.S.A.	2 months
D. N. Naik	U.S.A.	1 week
R. Mitra	U.S.A.	1 week
R. Mukerjee	India	6 months
M. B. Rao	U.S.A.	2 months
D. N. Shanbhag	U.K.	1 months
C. R. Sastry	U.S.A.	6 months
L. C. Zhao	China	3 months
B. Zhou	U.S.A.	1 year